

ALESSANDRO VOLTA

His “pile,” or battery, opened the age of electric power and settled his celebrated argument with Luigi Galvani. Curiously he then played no part in the epochal developments that his invention made possible

by Giorgio de Santillana

It is difficult to appreciate now, when electricity is so commonplace, what a marvel and mystery it was only 200 years ago. By the same token it is not easy to evoke a clear picture of the situation that confronted the early investigators of electrical phenomena. Electricity manifested itself in ways that were sometimes dramatic but that were also somewhat peculiar, for example in lightning or in amber rubbed with wool. Ascertaining the laws that governed its behavior was a process of groping by trial and error aided occasionally by a flash of intuition.

One can recapture some of the mystification of those times and some of the excitement of dispelling it by retracing the intellectual steps of an early investigator of electricity. Such a man was the Italian physicist Alessandro Volta, whose involvement in a major controversy with his countryman Luigi Galvani led him to construct his famous “pile”—the first electric battery and the first source of continuous electricity. With this device he opened the age of electricity, although he himself took little part in the flood of developments that followed quickly on his invention.

Volta was born on February 18, 1745, in the ancient Lombard town of Como. He had four brothers, three of whom became priests, and four sisters, two of whom became nuns. His father, Filippo, had himself been in the Jesuit order for 11 years before deciding at the age of 41 to marry a girl of 19. Filippo Volta was of noble birth, but he was a poor manager of the family funds. Years later Alessandro wrote: “My father owned nothing except a small dwelling worth about 14,000 lire; and he left behind him 17,000 lire of debt.”

As a child Alessandro was a source of concern to his family. He seemed dull-witted and was so slow in learning

to talk (he said nothing until he was four) that his parents decided he was a mute. At four his mind ignited; by seven he was regarded as being exceptionally bright in school. After Alessandro became famous his father said: “We had a jewel in the house but did not know it.”

Because of his family’s straitened circumstances Volta received his education through the endeavors of relatives in the church. From them and from his immediate family he was under pressure to enter the priesthood. He was intensely curious about natural phenomena, however, and by the time he was 14 he knew that he wanted to be a physicist. He also expressed the opinion that there were so many priests, nuns, monsignors and archdeacons in the family that it was unnecessary for him to aid in sanctifying it.

Volta’s early interest in nature did not detract from literary inclinations that he maintained throughout his life. His excellent classical education had made him well versed in Latin poetry. He once composed a long Latin poem on nature and science; it dwelt particularly on the researches of Joseph Priestley and also praised Benjamin Franklin and James Watt. The poem has considerable literary merit; the ear attuned to Latin verse will detect in Volta’s lines an echo of Lucretius.

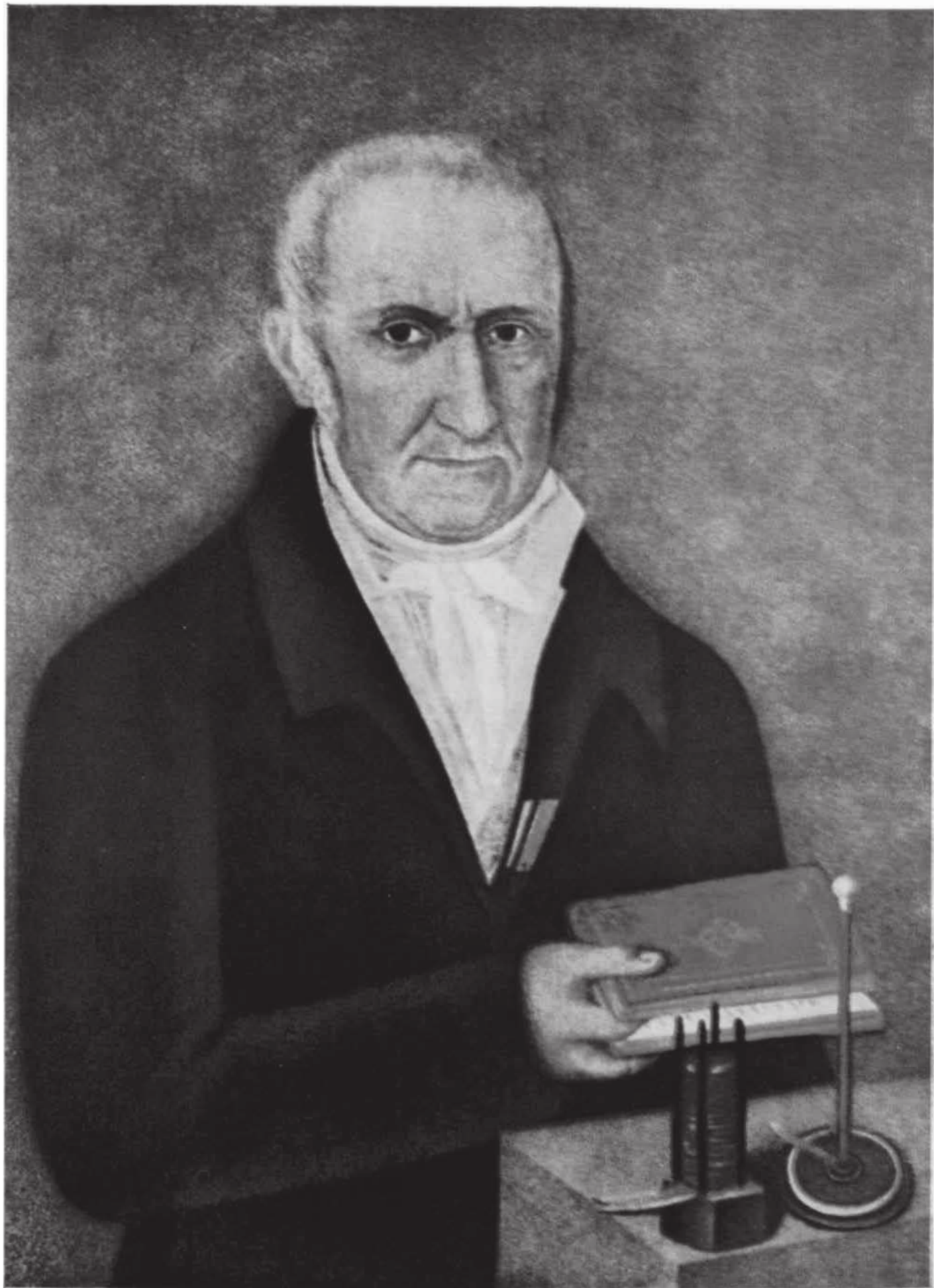
When he was 16, Volta was much under the influence of an older friend, the Canon Gattoni, who provided him with his first experimental equipment. Volta did not, however, share Gattoni’s orthodox views. He went so far as to write his friend a long dialogue designed to prove the heresy that not only men but also animals have souls.

The same adventurous turn of mind is apparent in Volta’s first published scientific paper, *De vi attractiva ignis elec-*

trici (Concerning the attractive force of electric fire). Written when Volta was 24, the paper was addressed to Giovanni Battista Beccaria, professor of physics at the University of Turin and a prominent experimenter in electrostatics. In it Volta undertook to show that all electrical phenomena can be attributed to one fluid or force that is akin to, if not identical with, universal gravitation.

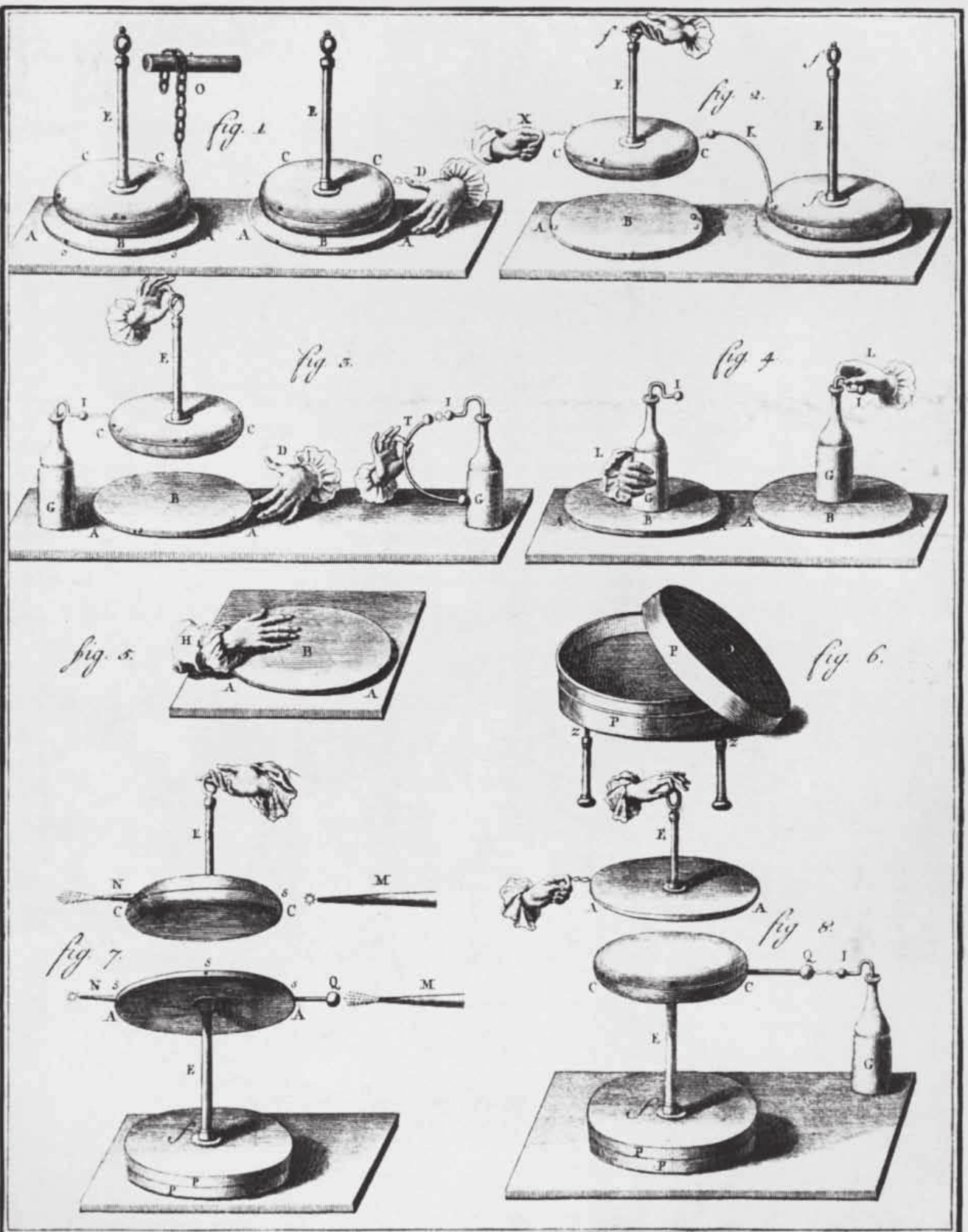
That was the last of Volta’s flights of speculation. His basic drive was for experimentation, and it soon led him to master the technique of basing conclusions on experimental findings. Even by the time his first paper was published he had been experimenting with electricity for several years. He was 18 when he began a correspondence with a respected French physicist and investigator of electrical phenomena, the Abbé Antoine Nollet.

Electrical science was of course in its infancy when Volta took it up. Several investigators had discovered during the preceding century that a number of substances behaved like amber when they were rubbed. In 1660 Otto von Guericke had built the first machine for generating an electric charge; it was a sulfur ball turned by a crank and charged by friction. In 1733 this invention, together with the discovery four years earlier that electricity would flow from one place to another through a suitable conductor, led Nollet and Charles François de Cisternay Du Fay to perform an engaging experiment that involved their own bodies. Du Fay was suspended horizontally by silk cords in a dark room and charged up with an electric machine of the von Guericke type; when Nollet touched him, he emitted large sparks. The experiment caught the fancy of the French court, where



LAST PORTRAIT OF VOLTA shows him in old age with representations of two of his inventions: the pile and the electrophorus.

The date of the portrait and the name of the artist are unknown, although the time was about 1820. Volta died in 1827, aged 82.



VOLTA'S ELECTROPHORUS was his first important invention. He announced it in a letter of 1775 to Joseph Priestley, accompanying the letter with illustrations similar to these, which appeared in a publication of the time. The apparatus consisted of a lower and an upper metal plate (A and C) separated by a disk (B) of nonconducting material such as resin. The resin was given a

negative charge by friction, and a positive charge was induced in the upper plate when it was placed on the resin and then grounded and lifted off. Thereafter the upper plate could be charged repeatedly by placing it on the resin and lifting it. The electrophorus was thus a replenishable source of static electricity, which earlier investigators had obtained only by direct friction.

conducting shocks from one person to another became something of a fad.

Du Fay found in another experiment that objects charged from a glass tube repelled each other but attracted objects charged from a rod of resin. The finding led him to two fundamental conclusions: that there are two kinds of electricity (in this he was not quite correct) and that like charges repel but unlike charges attract. Not long afterward the invention of the Leyden jar showed that electricity could be stored. Many investigators, accidentally or deliberately discharging Leyden jars by touching them, received numbing shocks. Shocks were routine occupational hazards for the early investigators of electricity; one wonders how they had the courage to persevere.

By this time Franklin had begun his electrical investigations, and he soon became the most important figure among the early theoreticians of electricity. From his experiments with the Leyden jar and other apparatus he concluded that the two kinds of electricity were two aspects of a single force: one was an excess of the force and the other a deficiency. It was he who bestowed the name "positive" on the former and "negative" on the latter; he could not know, of course, that the condition he called positive actually represented a deficiency of electrons and the condition he called negative represented an excess of them. Franklin's famous kite experiment, which led to the development of lightning rods, was conducted in 1752. From then on electrical theory had an almost magical import. Man had controlled lightning.

It was against this background that the youthful Volta began his investigations in 1763. For the next decade, however, he devoted himself mainly to his studies. In 1774 he became superintendent of the Royal School in Como. Soon he was called to the chair of physics at the University of Pavia, thanks to the protection of the Austrian emperor, who was then ruler of northern Italy. By that time he had taken on the personal characteristics often used to describe him. He was a handsome, strapping six-footer; affable and outgoing; fond of the outdoors; not disdainful of ordinary pastimes with ordinary people but very much a notable of his own city, personally acquainted with the foremost men of Europe; carefully conservative in his views and soberly objective in his interests.

In 1774 Volta made his first important contribution to electrical science with his invention of the "electropho-

rus," which provided experimenters for the first time with a steady, replenishable supply of static electricity. The device worked on the novel principle of electrostatic induction instead of on the direct application of friction required to produce a charge in earlier apparatus. It consisted of a cake of resin or some other nonconducting substance with one plate of metal below it and another plate above it; the upper plate had an insulated handle and could be removed [see illustration on opposite page]. One removed the upper plate, charged the resin by friction and put the plate back. If one then grounded the upper plate by touching it, the negative charge of the resin would repel the electrons in the plate; they would travel to the ground and the plate would be left with an induced positive charge. Thereafter, by lifting the plate one created an electric potential. If one then touched the plate, it gave off a spark. When the plate was discharged, it could be recharged in the same manner; the process could be repeated indefinitely. Describing the electrophorus in a letter of 1775 to Priestley, Volta wrote: "I present to you a body which, electrified only once for a short time and not strongly, will never more lose its electricity, and will obstinately maintain the

live force of its indications, even if it is touched again and again."

It is indicative of Volta's wide-ranging curiosity that his next invention grew out of a fishing trip on Lake Maggiore. He observed the bubbles that rose to the surface of the water in marshy areas, gathered some of this marsh gas (now known to be methane) and found it to be inflammable. He began a series of experiments with the gas and developed his "eudiometer," which was a tube closed at one end. Gases were bubbled into the tube from the water and exploded with an electric spark. The device was to prove valuable in determining the volume of gases that combined. As Volta said later, if he had been able to collect the gases over mercury he would have described the composition of water. He simply did not have enough mercury.

Another of Volta's inventions, announced in 1782, was the condensing electroscope, which was a much more sensitive indicator of the presence of electricity than earlier devices. This invention grew out of work he had done to improve electrometers, the best of which had used the separation of gold leaves to detect electricity. The condensing electroscope resembled the electrophorus except that instead of a

**DE VI ATTRACTIVA
IGNIS ELECTRICI,
AC PHAENOMENIS INDE PENDENTIBUS
ALEXANDRI VOLTÆ
PATRICII NOVO-COMENSIS
AD JOANNEM BAPTISTAM
BECCARIAM
EX SCHOLIS PIIS
IN REGIA TAURINENSI UNIVERSITATE
MATHEMATICÆ PROFESSOREM
DISSERTATIO EPISTOLARIS**



NOVO COMI, MDCCLXIX.

Typis Octavii Staurenghi Impressoris Episcopalis.
Superiorum Facultate.

*Scio aut, rati d. A. Volta leposibile a pp. LXV-VII
722*

FIRST PUBLISHED WORK by Volta was this paper of 1769. The note at bottom, by Volta's son Zanino, verifies that corrections on two pages of the paper were made by Volta.



LUIGI GALVANI is portrayed as he appeared in middle age. He and Volta were long in dispute over what Galvani called "animal electricity" and Volta called "metallic electricity."

slab of resin it used a thinner slab of weakly conductive material; as a result the upper plate could pick up a very small electric charge. This device was a kind of microscope of electricity, and it was what first brought Volta's name to the attention of other men of science. Later Volta used the condensing electroscope to perfect an early form of the kind of electrometer that determined an electric potential difference by balancing the electric force against the force of gravity.

By this time Volta was making frequent and extended trips abroad, a custom that brought him in contact with many prominent investigators and other figures. On one trip in 1771 he paid his respects to Voltaire, little imagining that not too long afterward Napoleon would stop in front of a wreath inscribed "To the Great Voltaire" and strike out the last letters to make it "To the Great Volta." While on a trip in 1789 Volta wrote home: "I have at last met the great Franklin." The acquaintances Volta made on these tours un-

doubtedly helped to fortify his reputation against the strains of the long controversy with Galvani.

Galvani, who was a physician and professor of anatomy at the University of Bologna, had begun experimenting with electricity in 1780. His interests included the effects of electric discharges on the nervous system of the frog. He discovered quite by accident in 1786 that the amputated hind legs of a frog would kick convulsively if they were made part of an electrical circuit. (On the occasion of the discovery the circuit was closed by one of Galvani's assistants, who happened to touch the crural nerve of the frog with a scalpel at a moment when an electric machine nearby gave off a spark.)

In many experiments with this phenomenon, extending over several years, Galvani found that it occurred when there was a nearby flash of lightning, and that the frogs' legs would twitch even in good weather if they were hung on an iron fence on a hook made of brass or copper. Pondering the phenom-

enon, Galvani recognized that it could be explained in one of two ways. Either electricity was a special animal property, in which case the outside influences merely caused the property to manifest itself, or the contact of two metals brought on the kicking, in which case the legs merely acted as an indicator of an outside charge. Galvani decided that it was the former: the animal tissue contained a vital force, which he called "animal electricity."

He published his results in 1791, and they created a sensation. Apparently he had found a key to the mystery of life. Among those impressed by the results was Galvani's friend Volta, to whom Galvani had sent one of the dozen copies of the paper, which he had had printed as a pamphlet.

At first Volta thought, with Galvani, that there was some kind of electrical disproportion between nerve and muscle, and that when metal connected the nerve and muscle of a frog's leg, the balance was restored. As Volta experimented with the phenomenon, however, he began to have doubts. He observed that muscles would contract even when they were not part of an electrical circuit; they did so when electric contacts were merely applied to the nerve. Gradually he came to the view that more attention should be paid to the role of the metals.

The story has been told many times as a beautiful example of nature taking good sense by the hand and guiding it to discovery. This concept, however, does less than justice to the fearfully intricate situation with which the experimenters were confronted. True, there were lucky breaks, such as the discovery that the contact of copper hooks and iron railings gave the best contraction of the frogs' legs. That looks decisive now but it did not then. The situation remained a jungle of possibilities.

Such was the setting for one of the great decisions of history, a decision that involved nothing less than the turning point of the scientific revolution. Was the new force of the electric current a special aspect of life or did it arrive to found the technological era? To whom was to belong the only form of immortality permitted by fast-rolling oblivion, namely posterity's choice of his name to designate the fundamental electric unit?

It was only historic justice that the decision fell to Volta. Whereas Galvani stood for the old kind of biological sciences, Volta was the new kind of physi-

cist: quantitatively minded, even if he had no mathematics, and a master of the new experimental approach. He also had the modern ruggedness. Whereas the sensitive, tormented Galvani was a born victim of circumstances, Volta had the gift of impassive adjustment. On the advent of French power in Italy in 1796 Galvani refused the oath of allegiance on conscientious grounds and retired to a silent poverty, from which he was rescued too late by the generosity of the conqueror. Volta, although he resented the invasion, moved into the French orbit as soon as it was prudent to do so. That remained his pattern. Throughout his life storm upon storm of success was to break on that brow and leave it unlined. He went through life unmoved.

In his years of trial after 1792, however, he stood alone and found few to understand him. His opponent had taken 10 years to prepare his case, and the case was strong. Nature had even loaded the dice in Galvani's favor, inasmuch as there was in fact more than

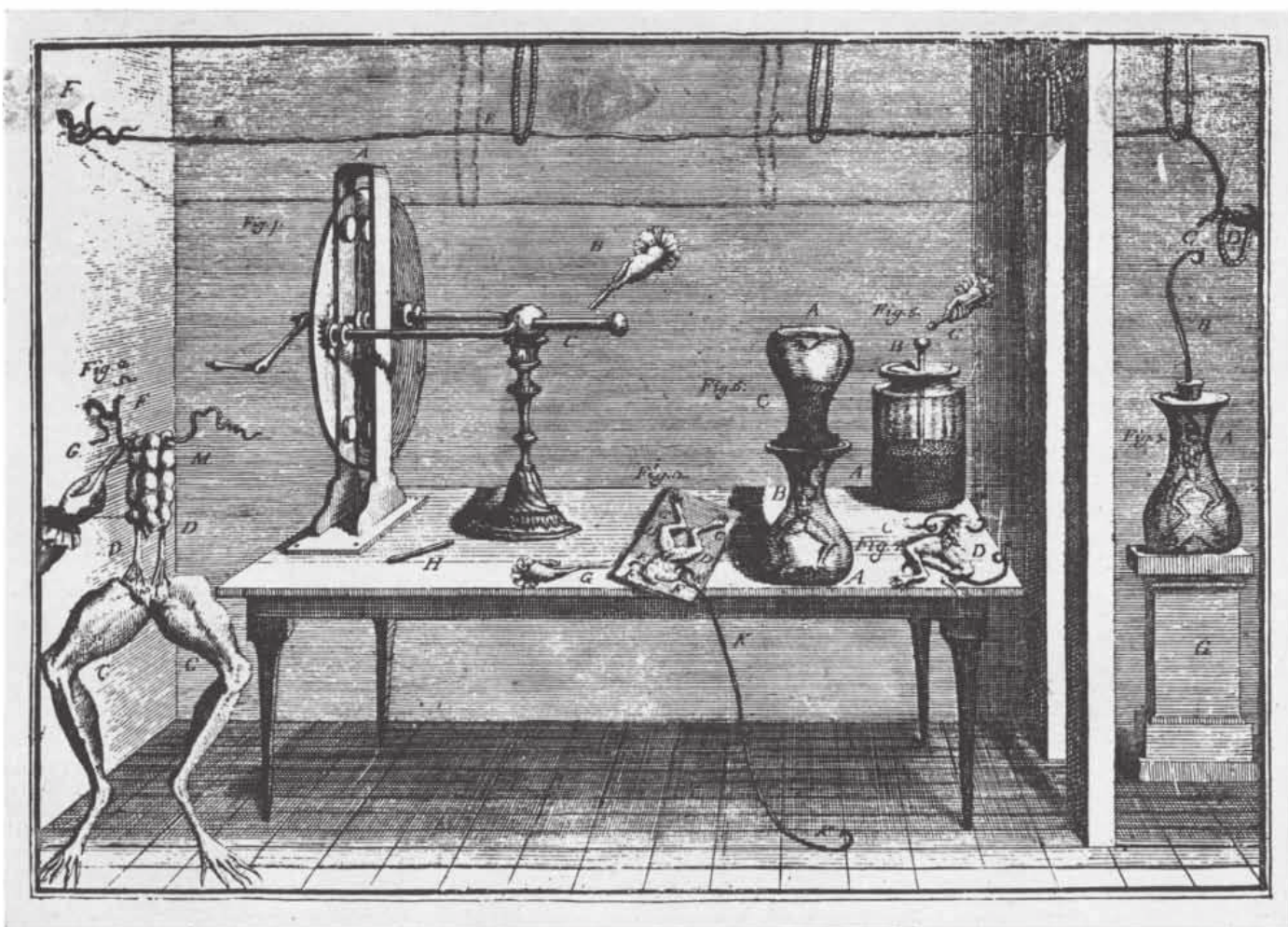
one electricity involved. There was an artificial electricity that could provide spectacular discharges, comparable to those of the electric eel, whereas it was still difficult to elicit even the smallest shocks and sparks from metallic electricity. There was also the electricity of the tissues that is now recorded by electrocardiographs. It was, to be sure, a feeble kind of electricity, but on the other hand nature had provided the most sensitive electroscopes in the form of frogs' legs; natural, or metallic, electricity did not get the right responses in the usual electrostatic instruments. Finally, the picture was blurred by actions at a distance and induction not yet rightly understood. As soon as Volta thought he had found a secure starting point in the presence of a bimetallic arc, Galvani was able to cut the ground from under him by showing that muscular contractions could be elicited without any metal in the circuit.

It took great firmness and clarity of mind to withstand the onslaught. "I know those gentlemen want me dead,"

Volta wrote to a friend in those days, "but I'll be damned if I'll oblige them." He had to work out his own electroscopes to detect metallic electricity, namely the sensitive tissues of his tongue and his eye; he had to show that it was the nerves and not the muscles that were stimulated. He concluded his second memoir firmly: "It is the difference of metals that does it."

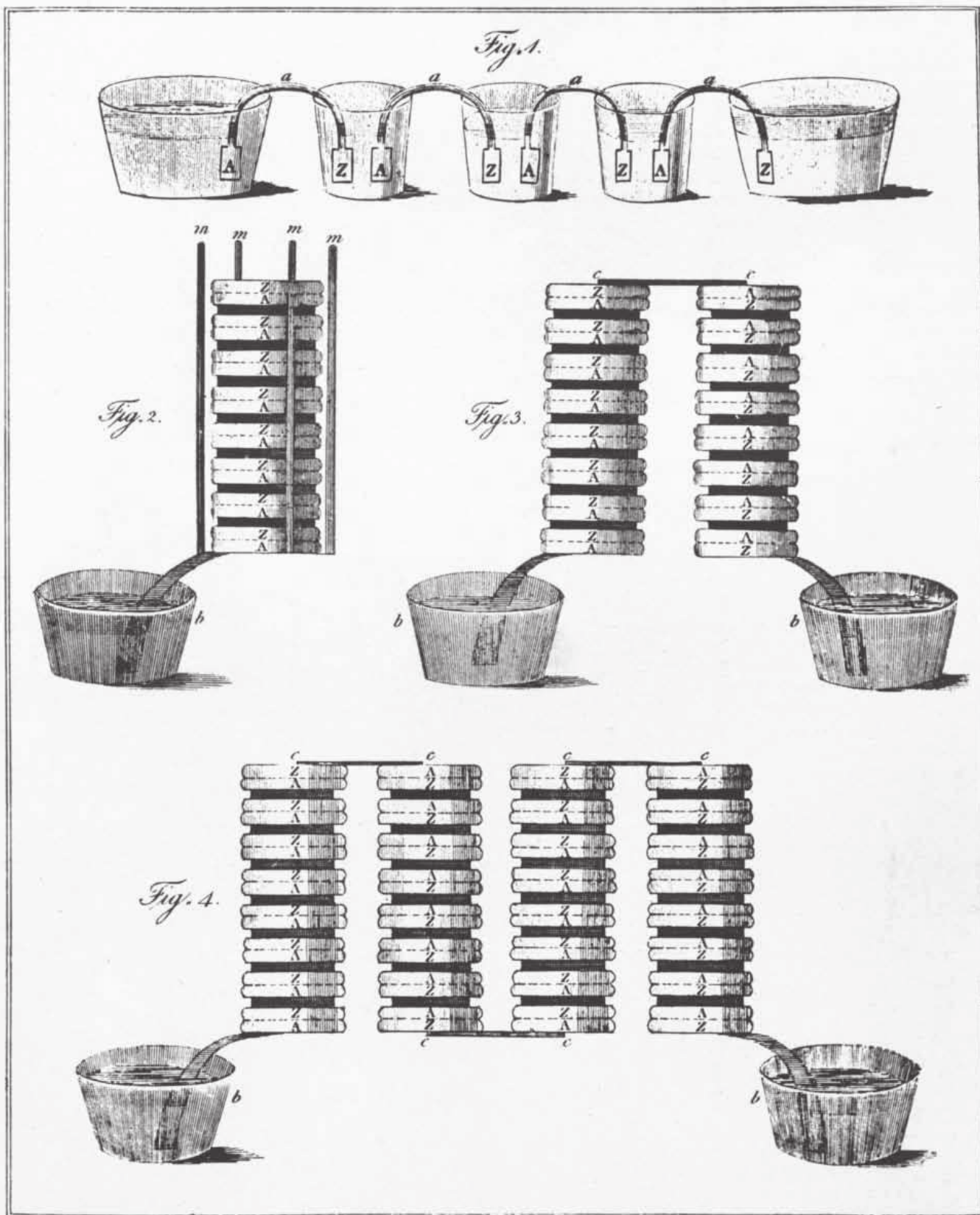
Pursuing this approach made it necessary for Volta to rebuild the whole structure of electrical concepts. It was here, in particular, that he had to define tension and distinguish it from quantity. "The quantity of electricity," he wrote, "which is put in motion by the contact of metals is not small, it is in fact considerable, but the current has so little tension that it gives no signs on the electrometer, and can be easily stopped by poor conductors. It is an ample flow, but a gentle one." This statement was descriptively perfect.

To Galvani's master argument that removed metals altogether, Volta re-



EXPERIMENTS BY GALVANI with frogs' legs are depicted in this engraving, which was one of four accompanying his publication of the results in 1791. He had found that dissected frogs' legs

would twitch when touched by metal in the presence of electricity. Among his sources of electricity were an electrostatic machine, shown at left on the table, and a Leyden jar, at right on the table.



FIRST ELECTRIC BATTERY, which Volta called "pile," is shown in the illustration that accompanied his announcement of the invention. The announcement was in the form of a letter to Sir Joseph Banks, president of the Royal Society of London; the letter was published in the *Philosophical Transactions of the Royal Society* in 1800. At top the battery appears in a form that Volta called a

"chain of cups." It consisted of dissimilar metals, such as silver (designated "A" for "argentum") and zinc (Z), immersed in salt water; "they are made all to communicate by forming them into a sort of chain, by means of so many metallic arcs." The lower figures show aspects of the "columnar" form of the battery, in which silver-zinc couples were separated by disks of moistened pasteboard.

plied by extending the concept of conductor and motor contact to bodies of the second class, as he called them, namely liquids. This concept led him to the problem of adding electromotive forces in chains of conductors. By moving now from electrokinetics to electrostatics, by ingeniously juggling his inadequate instruments and his puny charges, he managed at last to build up his pure contact forces to a tension detectable in the electrometer. Again it was a measuring procedure that led him to his goal. After having searched for two years for a means of multiplying the contact tension of metals by adding up contacts, he hit on his idea of the battery, which he communicated to Sir Joseph Banks, president of the Royal Society, in a letter dated March 20, 1800. The battery was originally a pile of disks: copper-zinc couples, each separated from the next by a disk of cardboard moistened with acidulated water. The 10-year battle had been won: electric power had come into the world.

Volta and Galvani both had their greatness and their limitations. Just as the unfortunate Galvani had invented galvanic electricity and believed its nature to be animal—a misconception that led his followers into the sands of vitalistic quackery and almost killed his discovery—so Volta in saving that discovery had actually discovered electrochemistry without knowing it. He stopped in sight of the promised land. He left it to Anthony Carlisle and William Nicholson of England to achieve within a few weeks the electrolysis of water. They had only to read the letter to Banks and build a battery. Volta never cared to venture into the immense new field. It is strange to think that he was still in his robust fifties when the tide of electrochemical discoveries broke on the world, when Humphry Davy electrolyzed the alkalies and produced the voltaic arc.

It is noteworthy that in a famous demonstration of the pile in Paris in 1801, with Napoleon present, Volta gave an absurd amount of attention to the ways of making his battery assume the appearance of an electric eel by dressing it in a skin. This was not silly gadgeteering, nor was it the cultural lag that made the creators of the railway try to imitate the coach-and-four. It was the final settling of the old quarrel with Galvani about animal electricity. Galvani's articulate nephew Giovanni Aldini had still been defending the cause of galvanism after Galvani's death, so Volta had reason for his atti-



Interpretation by William Thonson

Reactor Materials Evaluation

PROBLEM: The application of electron microscope and metallographic techniques to the basic analysis of the microstructure of high-temperature, gas-cooled, graphite reactor components. Of particular interest are fuel migration, matrix integrity, and cladding efficiency. This is typical of many such problems facing the materials evaluation scientists in the Los Alamos Scientific Laboratory.

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tude. He had knocked down the idea, but he still had to drag it out.

It would be easy to conclude that this last act of the episode is an example of a mind remaining polarized on its moment of creation. Yet nothing in history is as simple as that. One should see that Volta had to go on playing his part in the drama. He had conquered a strongpoint; it then became his business to hold it in the troubled times ahead. That was why his thought continued to have a powerful influence on the next generation. He stood for good method against adventure.

Davy, as early as November, 1800, had concluded that the power of action of the battery is "in great measure proportional to the power of the conducting fluid substance between the double plates to oxydate the zinc." Volta, however, had already taken the position that the mere contact of two metals was enough. In fact, he supplied what seemed to be a convincing proof. Taking a disk of copper and one of zinc, he held each by an insulating handle and applied them to each other for an in-

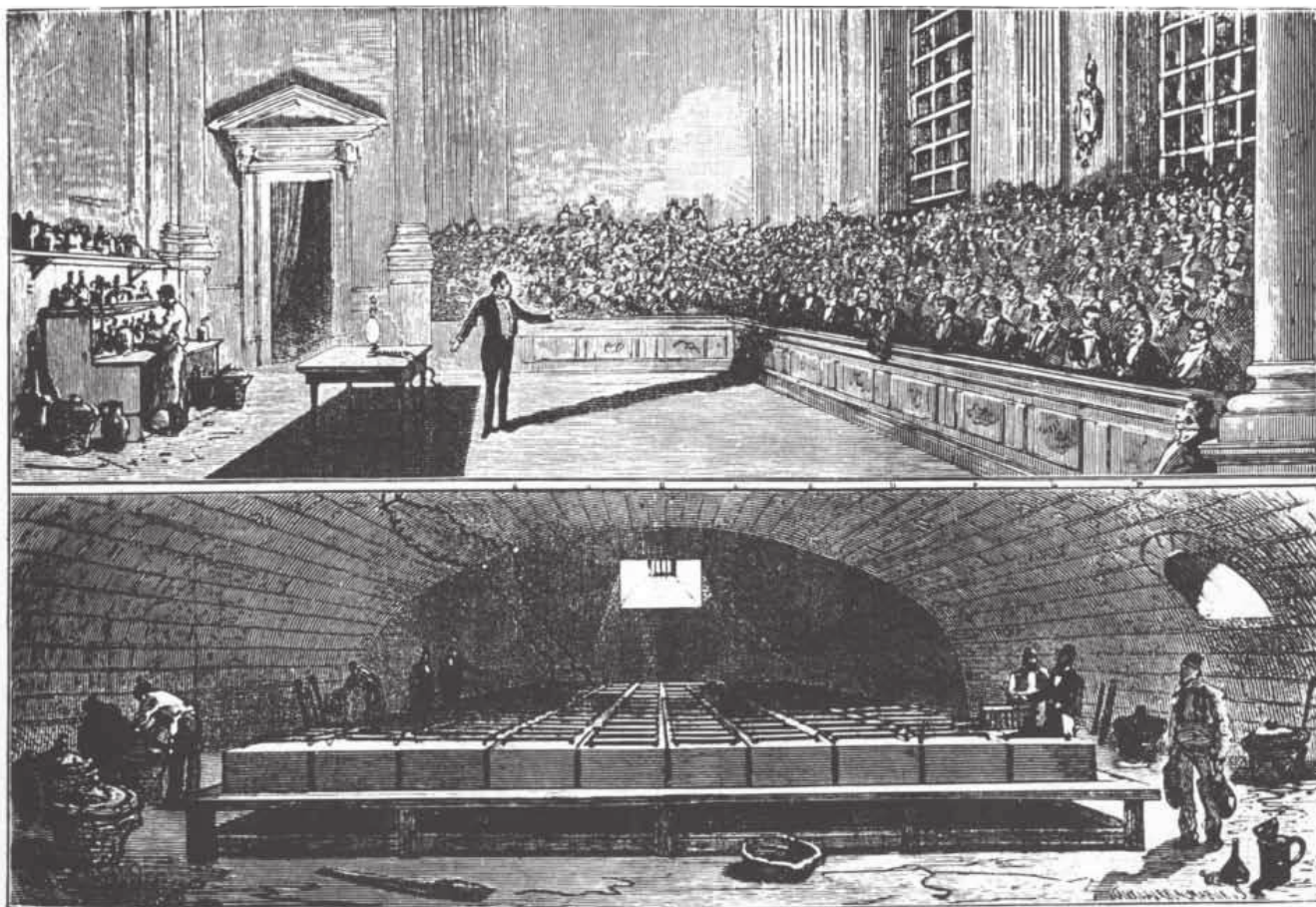
stant. After the disks had been separated, the electroscope showed that they were electrified with opposite signs. Volta fully understood the phenomenon and explained the impossibility of constructing a pile from disks of metal without making use of moist separators. He showed in 1801 that, in a pile of disks of different metals in direct contact, the disks at the top and the bottom of the pile will be in the same state as disks in direct contact. For him the moist layers only played the part of conductors.

How, then, did he conceive the operation of the pile? Consider first a disk of zinc laid on a disk of copper resting on an insulated support. One may assume, from the single-fluid theory that Volta had learned from Franklin, that electricity will be driven from the copper to the zinc. One may then represent the tension of the copper as $-1/2$ and that of the zinc as $+1/2$, the difference being arbitrarily taken as 1, and the sum, because of the insulation, as 0. In this line of reasoning Volta was using "tension" for an amalgam of two

ideas that today are distinct, namely charge and potential.

Now, if one places another disk of copper on top of the zinc, with moist pasteboard between, there will be contact only through the moist conductor, and the copper will receive a charge from the zinc. The states will be represented by $-2/3$ for the bottom copper disk, $+1/3$ for the zinc and $+1/3$ for the top copper disk, giving a sum of 0 as before. If one places another disk of zinc atop the pile, the states will be represented by -1 for the bottom copper disk, 0 for the intermediate pair of disks and $+1$ for the top zinc disk. This is how the tension will increase as the pile is built up.

It is clear that the image behind the theory is that of the Leyden jar, an early form of the condenser. The experimenter will receive the shock of a discharge when he touches the top and bottom disks. The great difficulty that remained (and Volta was aware of it) was that the pile does not discharge itself as a condenser does; it maintains its state. "This endless circulation or per-



ELECTRIC ARC LIGHT, which became known as the voltaic arc, is shown as demonstrated by Humphry Davy at the Royal Institution in London. His source of power was a 2,000-cell voltaic battery

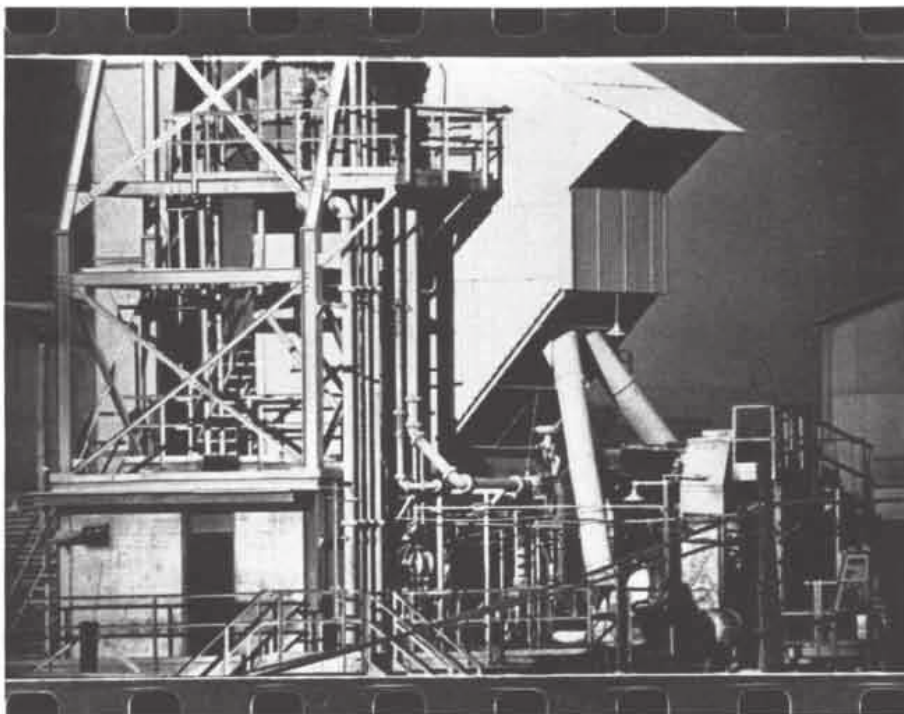
built in the basement with money from public subscription. He used charcoal electrodes to produce the arc; a contemporary account said the light was "so intense as to resemble that of the sun."

petual motion of the electric fluid," Volta wrote, "may seem paradoxical, and may prove inexplicable, but it is nonetheless real." His neat mind recoiled from the obscurities of chemical action. This was true even when he came to deal with it in explaining that bane of early experimenters: the polarization of batteries. Yet he went on avoiding the thought of any link between chemical change and electric force.

Volta's rigor may appear obdurate and sterile to the modern mind armed with hindsight. No doubt it did bar him from the exciting realm of new discoveries that blossomed during his lifetime. One should consider, however, how bewildering the situation in electricity was then, and what misleading speculations it could prompt in lieu of sound theories. Volta stood for clarity and prudence. The same virtues that had guided him surely through the jungle of galvanism now acted as a brake.

Typically enough, at 50, when he had completed his work, Volta made up his mind to marry. Even more typically, he went to two of his clerical friends for advice. For 25 years he had had a liaison with a well-known singer known as Mademoiselle Paris; should he regularize the situation? One of the clerics thought he should. Volta, however, had habitually followed the advice of a brother who was an archdeacon. Taking the brother's advice, he married a woman of good family; she has been described as ill-favored but implacable in the administration of the family estate. Volta now settled down to a new life as a father, a senator and eventually a count of the Napoleonic empire.

One should probably not call him to task for the accommodations of his old age. With the fall of Napoleon, Volta did what everyone else in his region did: he quietly returned to being a good Austrian subject. The Austrians were old protectors, after all, and they were ready to forgive. Volta was not of the stuff that martyrs are made of, and the new time of nations in their birth pangs—with its heroic stands, its exiles, its romantic dreams and its braving of police persecution—was not for him. He was a man of the old order and wanted to live out his time on his country estate in Camnago. It was, perhaps, a not unattractive end. There is poetic symmetry in the fact that the protagonist in the most far-reaching of all revolutions—compared to which the whole Napoleonic adventure was mere sound and fury—should have been a quiet conservative.



We print the sprocket holes here to show exactly what the Questar Field Model below impressed on the Tri-X negative. Time, 1/500 second. Normal development with D-76. Some of the background buildings are partially obscured by smoke.



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